PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark Office, PCT
2011 South Clark Place Room CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 27 February 2001 (27.02.01)	
International application No. PCT/NZ00/00105	**Applicant's or agent's file reference** P427402 BMP
International filing date (day/month/year) 21 June 2000 (21.06.00)	**Priority date** (day/month/year) 21 June 1999 (21.06.99)
Applicant DUNCAN, Gerald, David et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

28 December 2000 (28.12.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Elisabeth KÖNIG Telephone No.: (41-22) 338.83.38

51018323/

Copy for the Elected Office (EO/US)

PCT/NZ0

PATENT COOPERATION TREATY

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

A J PARK
6th Floor
Huddart Parker Building
Post Office Square
P.O. Box 949
Wellington 6015
NOUVELLE-ZÉLANDE

Date of mailing (day/month/year) 06 février 2002 (06.02.02)	
Applicant's or agent's file reference P427402 BMP	**IMPORTANT NOTIFICATION**
International application No. PCT/NZ00/00105	**International filing date** (day/month/year) 21 juin 2000 (21.06.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
FISCHER & PAYKEL LIMITED 78 Springs Road East Tamaki Auckland New Zealand	NZ	NZ
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[ ] the person [X] the name [ ] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
FISHER & PAYKEL LIMITED 78 Springs Road East Tamaki Auckland New Zealand	NZ	NZ
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[ ] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer François BAECHLE Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

A J PARK
6th Floor
Huddart Parker Building
Post Office Square
P.O. Box 949
Wellington 6015
NOUVELLE-ZÉLANDE

Date of mailing (day/month/year) 30 January 2001 (30.01.01)	
Applicant's or agent's file reference P427402 BMP	**IMPORTANT NOTIFICATION**
International application No. PCT/NZ00/00105	**International filing date** (day/month/year) 21 June 2000 (21.06.00)

1. The following indications appeared on record concerning:

☐ the applicant ☐ the inventor ☒ the agent ☐ the common representative

Name and Address	State of Nationality	State of Residence
PARK, A., J. 6th Floor Huddart Parker Building Post Office Square P.O. Box 949 Wellington 6015 New Zealand	Telephone No. 64 9 356 6996 Facsimile No. 64 9 356 6990 Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

☐ the person ☒ the name ☐ the address ☐ the nationality ☐ the residence

Name and Address	State of Nationality	State of Residence
A J PARK 6th Floor Huddart Parker Building Post Office Square P.O. Box 949 Wellington 6015 New Zealand	Telephone No. 64 9 356 6996 Facsimile No. 64 9 356 6990 Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

☒ the receiving Office
☒ the International Searching Authority
☐ the International Preliminary Examining Authority
☒ the designated Offices concerned
☐ the elected Offices concerned
☐ other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer David Lopez-Ramirez Telephone No.: (41-22) 338.83.38

REC'D 28 MAR 2001
WIPO PCT

14

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P427402BMP	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. **PCT/NZ00/00105**	International Filing Date *(day/month/year)* 21 June 2000	Priority Date *(day/month/year)* 21 June 1999

International Patent Classification (IPC) or national classification and IPC

Int. Cl. ^{7} H02K 33/00, 41/02, F04B 17/04, 31/00

Applicant

FISHER & PAYKEL LIMITED et al

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of sheet(s).

3. This report contains indications relating to the following items:

I	☒	Basis of the report
II	☐	Priority
III	☐	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	☒	Lack of unity of invention
V	☒	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	☐	Certain documents cited
VII	☐	Certain defects in the international application
VIII	☐	Certain observations on the international application

Date of submission of the demand	Date of completion of the report
28 December 2000	19 March 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer **SOOSA GNANASINGHAM** Telephone No. (02) 6283 2172

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/NZ00/00105

I. Basis of the report

1. With regard to the **elements** of the international application:*

[X] the international application as originally filed.

[ ] the description, pages , as originally filed,
pages , filed with the demand,
pages , received on with the letter of

[ ] the claims, pages , as originally filed,
pages , as amended (together with any statement) under Article 19,
pages , filed with the demand,
pages , received on with the letter of

[ ] the drawings, pages , as originally filed,
pages , filed with the demand,
pages , received on with the letter of

[ ] the sequence listing part of the description:
pages , as originally filed
pages , filed with the demand
pages , received on with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language which is:

[ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

[ ] the language of publication of the international application (under Rule 48.3(b)).

[ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, was on the basis of the sequence listing:

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. [ ] The amendments have resulted in the cancellation of:

[ ] the description, pages
[ ] the claims, Nos.
[ ] the drawings, sheets/fig.

5. [ ] This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/NZ00/00105

IV. Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

- [ ] restricted the claims.
- [X] paid additional fees.
- [ ] paid additional fees under protest.
- [ ] neither restricted nor paid additional fees.

2. [ ] This Authority found that the requirement of unity of invention is not complied with and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

- [ ] complied with.
- [X] not complied with for the following reasons:

The different inventions are:

1. Claims 1-5 are directed to an electric linear motor for driving a reciprocating load wherein energising means controlling means for producing alternating flux in the stator core is such that one end of a permanent magnet of the armature passes outside of the air gap in the stator core.

2. Claims 6-24 are directed to a vapour compressor comprising a piston reciprocating within a cylinder, a linear brushless DC motor with at least one winding coupled to the piston, electronically commutating said winding from a DC supply to reciprocate the piston, commutations timed to drive said piston at the resonant frequency of the vibrating system, which frequency varies with the vapour pressure of the compressor, wherein the parameter determining the current supply during commutation is limited to a value which is a function of said resonant frequency.

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

- [X] all parts.
- [ ] the parts relating to claims Nos.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims **1-26**	**YES**
	Claims	**NO**
Inventive step (IS)	Claims **1-26**	**YES**
	Claims	**NO**
Industrial applicability (IA)	Claims **1-26**	**YES**
	Claims	**NO**

2. Citations and explanations (Rule 70.7)

Novelty (N) & Inventive Step: Claims 1-5

The closest prior art cited was :

EP 246468 A

EP 246468 is directed to a cooling system, which uses a linear motor to run the compressor. The present claims differ from EP 246468 in that energisation means for controlling means for producing alternative flux is such that at least one end of at least one magnet passes outside the region of uniform flux density. Further, the claimed invention is not obvious to a person skilled in the art in the light of common general knowledge by itself or in combination with the above document.

Novelty (N) & Inventive step: Claims 6-24

The closest prior art was found in the following documents:

EP 652632A
EP 766005A
EP 726394A

However none these documents teach or fairly suggest a vapour compressor with current control means as defined in claim 6 or a method of limiting current in a vapour compressor as defined in claim 15, characterised by the said means or method being dependent upon the resonant frequency of the vibrating system.

Further, the claimed invention is not obvious in the light of any of the above documents nor disclosed in any obvious combination, nor would the claimed invention be obvious to a person skilled in the art in the light of common general knowledge by itself or in combination with any of these documents.

Claims 1-26 are therefore novel and inventive and satisfy the requirements Article 33(2)-(3) of the PCT.

All of claims 1-26 satisfy the requirement of industrial applicability.

ATENT COOPERATION TREATY

From the:
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

A J PARK & SON
PO Box 949
WELLINGTON 6001
New Zealand

PCT

NOTIFICATION OF TRANSMITTAL OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing *day/month/year*	23 MAR 2001

Applicant's or agent's file reference P427402BMP	**IMPORTANT NOTIFICATION**

International Application No.	International Filing Date	Priority Date
PCT/NZ00/00105	21 June 2000	21 June 1999

Applicant

FISHER & PAYKEL LIMITED et al

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translations to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices)(Article 39(1))(see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide

Name and mailing address of the IPEA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	SOOSA GNANASINGHAM Telephone No. (02) 6283 2172

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P427402BMP	**FOR FURTHER ACTION** .	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. **PCT/NZ00/00105**	International Filing Date *(day/month/year)* 21 June 2000	Priority Date *(day/month/year)* 21 June 1999
International Patent Classification (IPC) or national classification and IPC **Int. Cl.** 7 H02K 33/00, 41/02, F04B 17/04, 31/00		
Applicant FISHER & PAYKEL LIMITED et al		

1. **This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.**

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

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I	☒	Basis of the report
II	☐	Priority
III	☐	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	☒	Lack of unity of invention
V	☒	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	☐	Certain documents cited
VII	☐	Certain defects in the international application
VIII	☐	Certain observations on the international application

Date of submission of the demand 28 December 2000	Date of completion of the report 19 March 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer **SOOSA GNANASINGHAM** Telephone No. (02) 6283 2172

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/NZ00/00105

I. Basis of the report

1. With regard to the **elements** of the international application:*

[X] the international application as originally filed.

[ ] the description, pages , as originally filed,
pages , filed with the demand,
pages , received on with the letter of

[ ] the claims, pages , as originally filed,
pages , as amended (together with any statement) under Article 19,
pages , filed with the demand,
pages , received on with the letter of

[ ] the drawings, pages , as originally filed,
pages , filed with the demand,
pages , received on with the letter of

[ ] the sequence listing part of the description:
pages , as originally filed
pages , filed with the demand
pages , received on with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
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[ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

[ ] the language of publication of the international application (under Rule 48.3(b)).

[ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, was on the basis of the sequence listing:

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. [ ] The amendments have resulted in the cancellation of:

[ ] the description, pages
[ ] the claims, Nos.
[ ] the drawings, sheets/fig.

5. [ ] This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

IV.	Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

   - [ ] restricted the claims.
   - [X] paid additional fees.
   - [ ] paid additional fees under protest.
   - [ ] neither restricted nor paid additional fees.

2. [ ] This Authority found that the requirement of unity of invention is not complied with and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

   - [ ] complied with.
   - [X] not complied with for the following reasons:

The different inventions are:

1. Claims 1-5 are directed to an electric linear motor for driving a reciprocating load wherein energising means controlling means for producing alternating flux in the stator core is such that one end of a permanent magnet of the armature passes outside of the air gap in the stator core.

2. Claims 6-24 are directed to a vapour compressor comprising a piston reciprocating within a cylinder, a linear brushless DC motor with at least one winding coupled to the piston, electronically commutating said winding from a DC supply to reciprocate the piston, commutations timed to drive said piston at the resonant frequency of the vibrating system, which frequency varies with the vapour pressure of the compressor, wherein the parameter determining the current supply during commutation is limited to a value which is a function of said resonant frequency.

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

   - [X] all parts.
   - [ ] the parts relating to claims Nos.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims 1-26	YES
	Claims	NO
Inventive step (IS)	Claims 1-26	YES
	Claims	NO
Industrial applicability (IA)	Claims 1-26	YES
	Claims	NO

2. Citations and explanations (Rule 70.7)

Novelty (N) & Inventive Step: Claims 1-5

The closest prior art cited was :

EP 246468 A

EP 246468 is directed to a cooling system, which uses a linear motor to run the compressor. The present claims differ from EP 246468 in that energisation means for controlling means for producing alternative flux is such that at least one end of at least one magnet passes outside the region of uniform flux density. Further, the claimed invention is not obvious to a person skilled in the art in the light of common general knowledge by itself or in combination with the above document.

Novelty (N) & Inventive step: Claims 6-24

The closest prior art was found in the following documents:

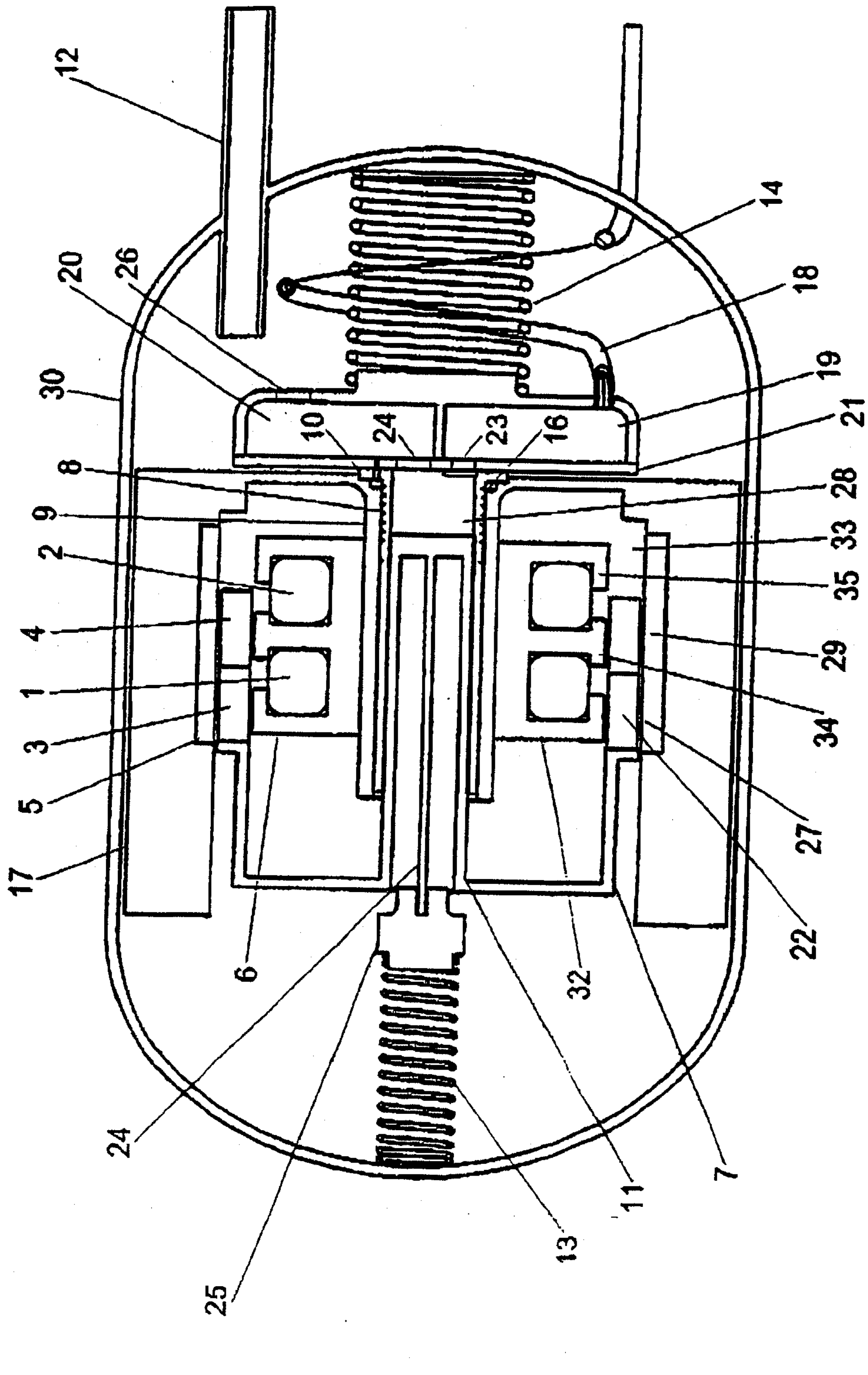
EP 652632A
EP 766005A
EP 726394A

However none these documents teach or fairly suggest a vapour compressor with current control means as defined in claim 6 or a method of limiting current in a vapour compressor as defined in claim 15, characterised by the said means or method being dependent upon the resonant frequency of the vibrating system.

Further, the claimed invention is not obvious in the light of any of the above documents nor disclosed in any obvious combination, nor would the claimed invention be obvious to a person skilled in the art in the light of common general knowledge by itself or in combination with any of these documents.

Claims 1-26 are therefore novel and inventive and satisfy the requirements Article 33(2)-(3) of the PCT.

All of claims 1-26 satisfy the requirement of industrial applicability.


12
20
26
30
8
9
2
4
1
3
5
17
6
24
25
13
11
7
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22
27
34
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35
33
28
21
19
18
14
10
24
23
16

FIG. 1

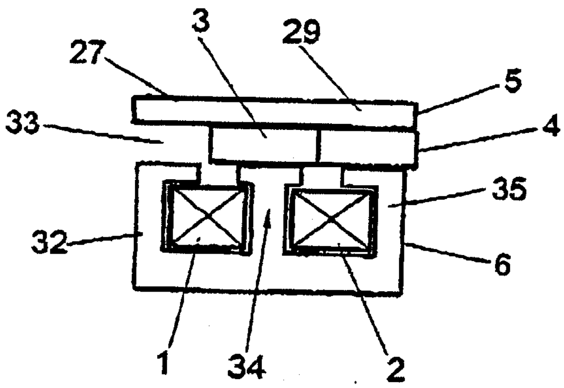


FIG. 2

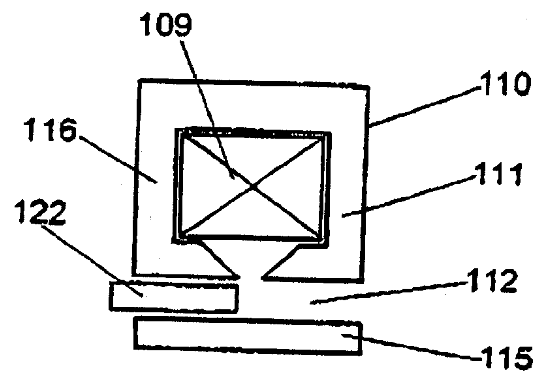


FIG. 3

FIG. 4

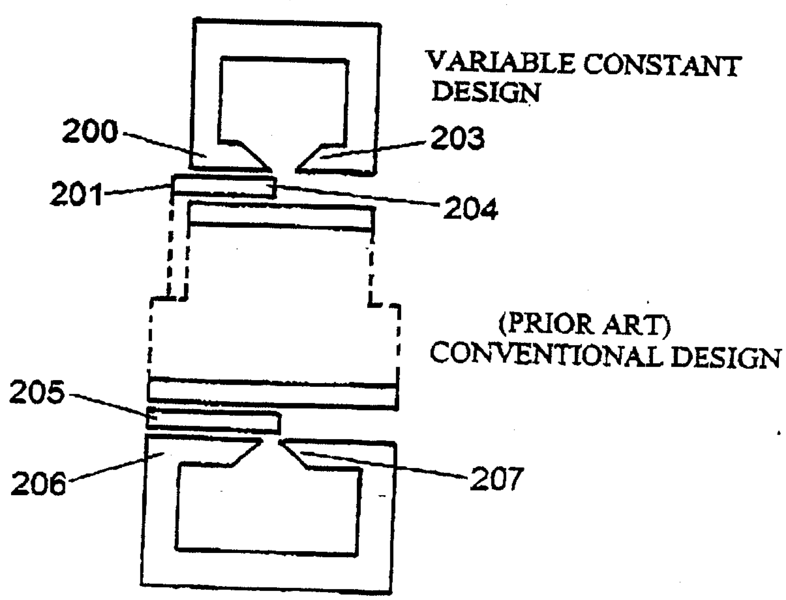


FIG. 5

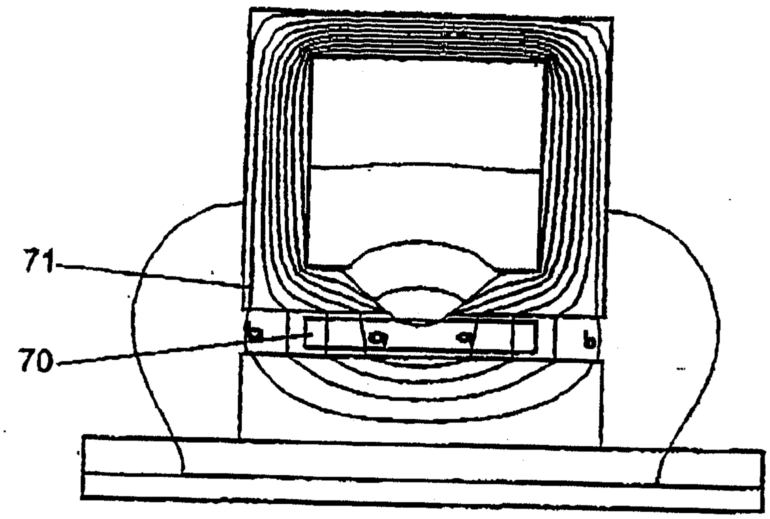
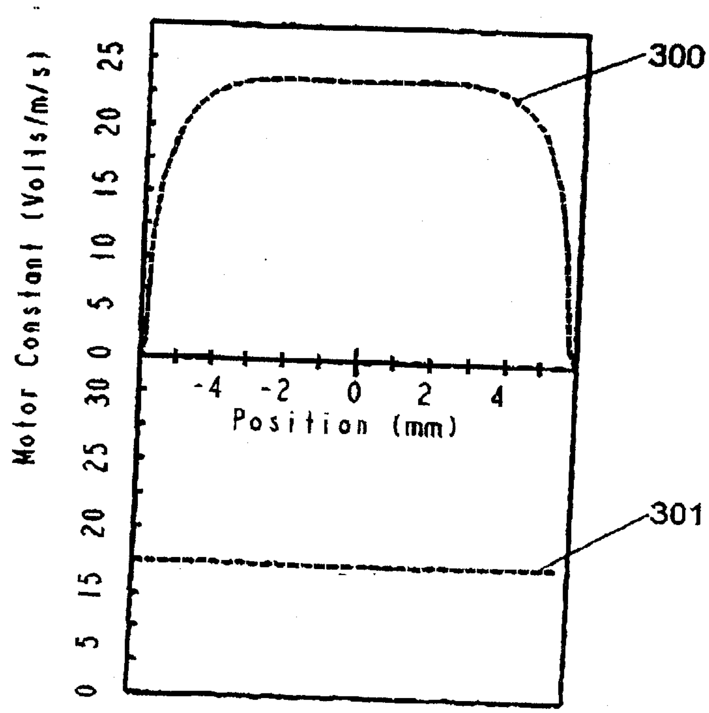

71
70
a
a
b
b

FIG. 6


300
301
Motor Constant (Volts/m/s)
0
5
10
15
20
25
30
-4
-2
0
2
4
Position (mm)

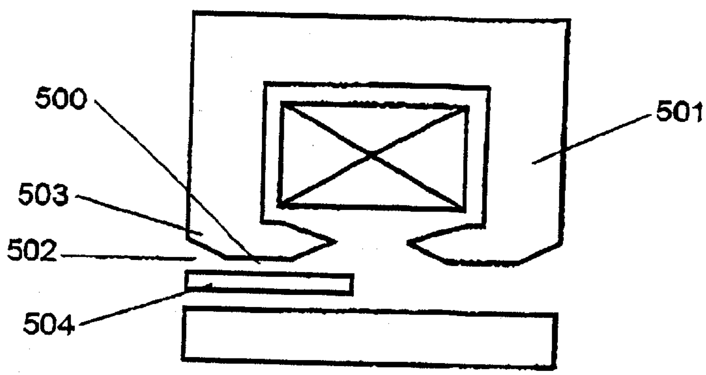


FIGURE 7

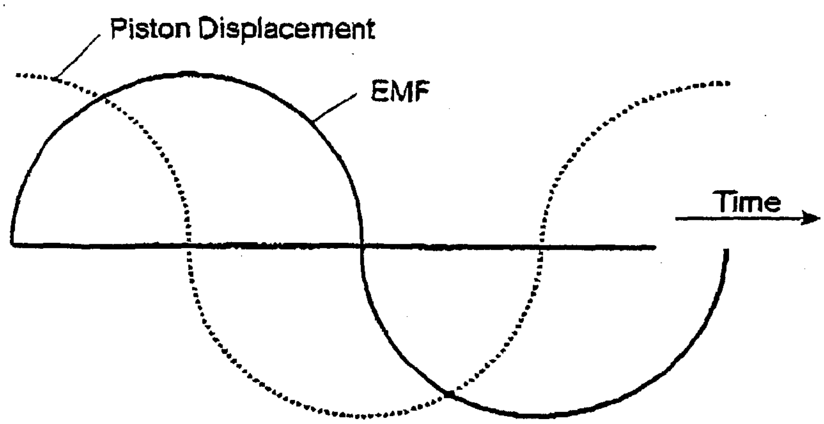


FIGURE 8a
Motor EMF and Displacement Waveforms

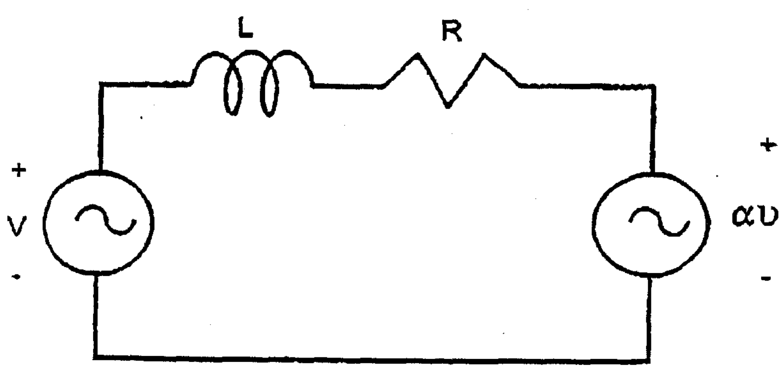


FIGURE 8b
Motor Equivalent Circuit

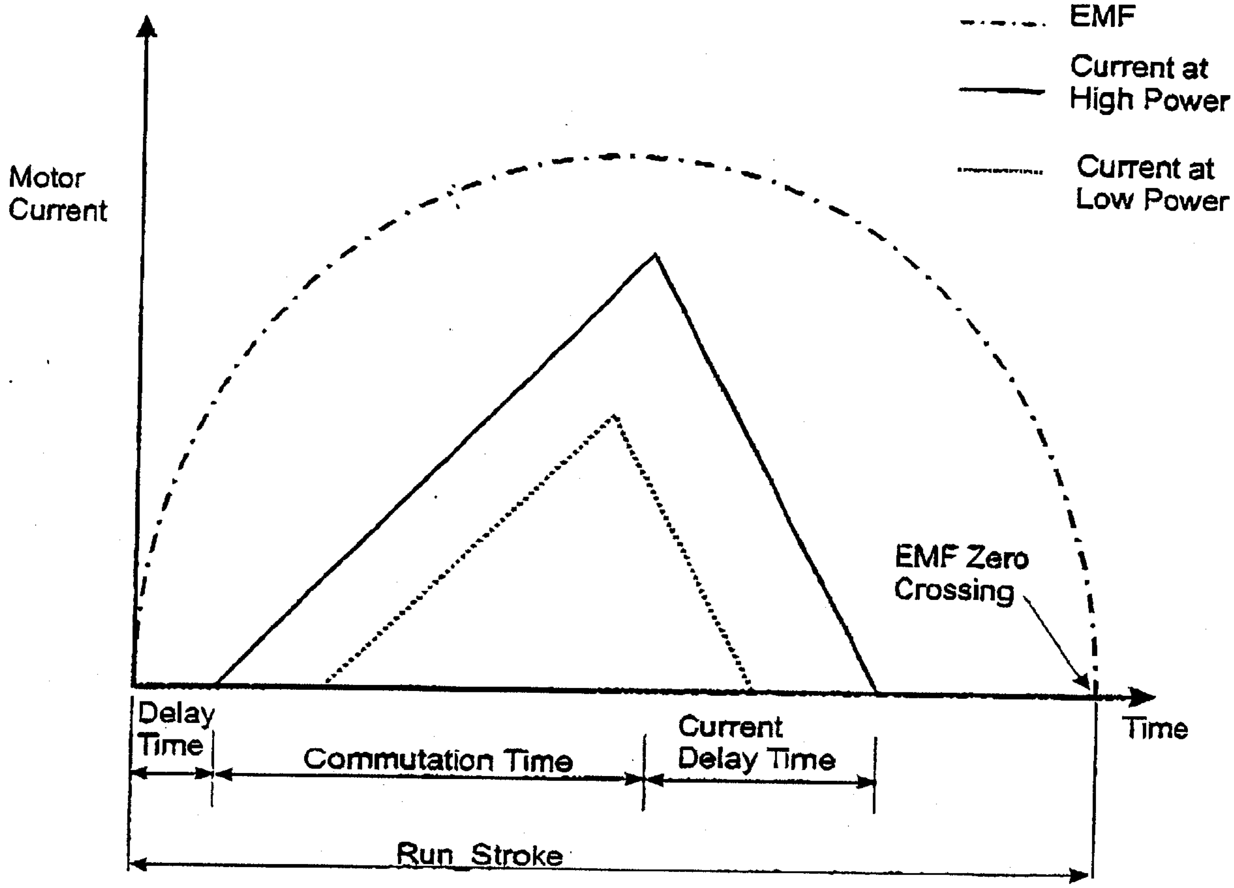


FIGURE 15
Motor Current Waveform and Timing

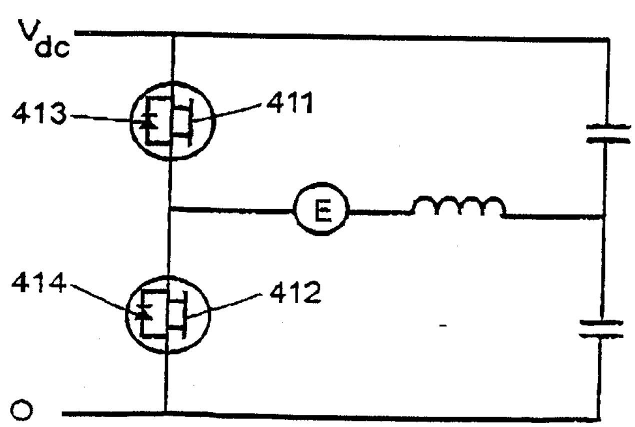


FIGURE 9

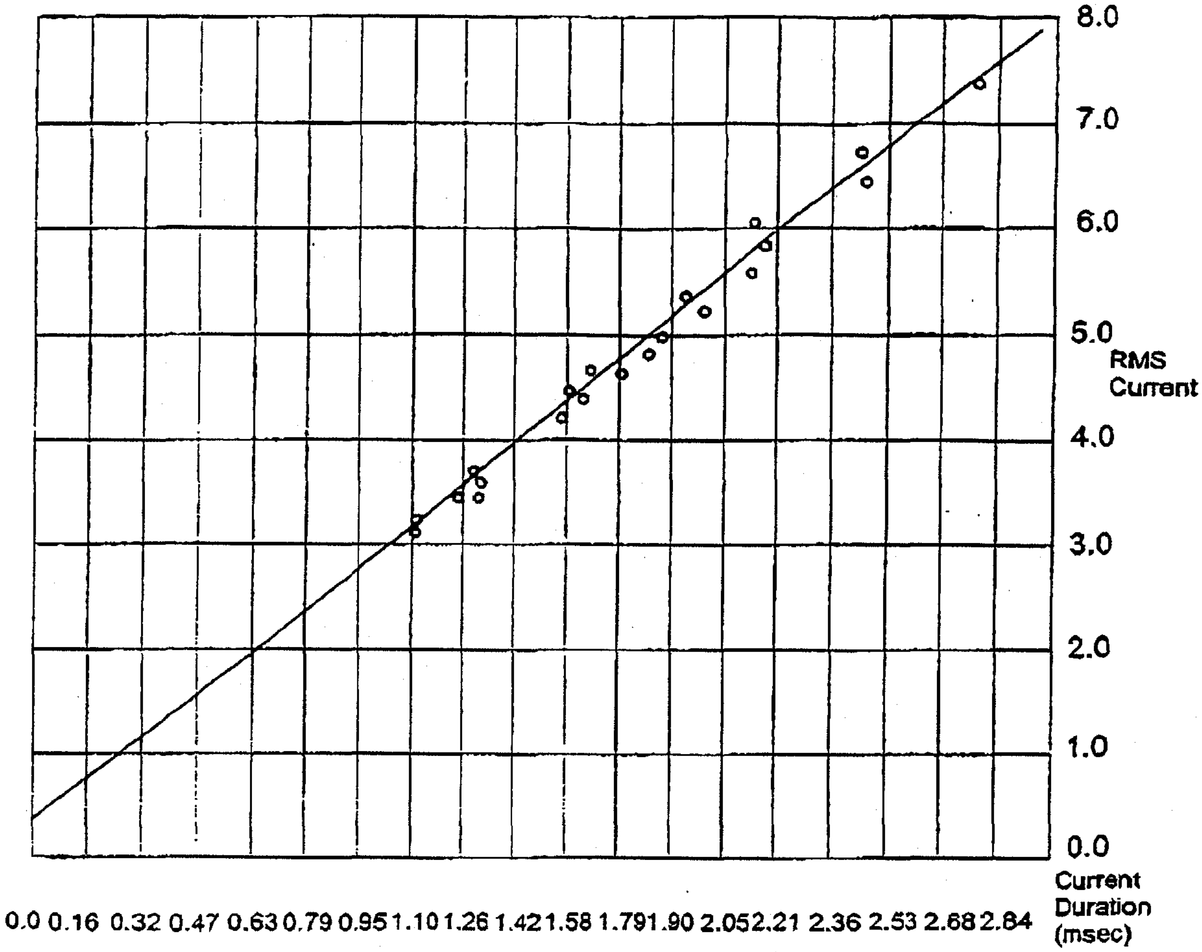

8.0
7.0
6.0
5.0
RMS Current
4.0
3.0
2.0
1.0
0.0
Current Duration (msec)
0.0 0.16 0.32 0.47 0.63 0.79 0.95 1.10 1.26 1.42 1.58 1.79 1.90 2.05 2.21 2.36 2.53 2.68 2.84

FIGURE 12

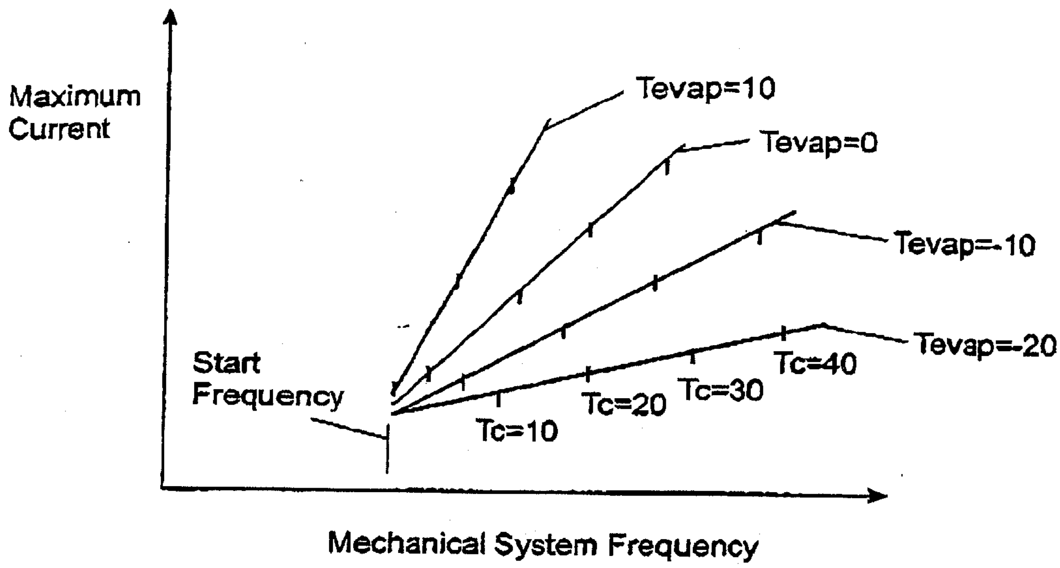


FIGURE 10

Maximum Current as a function of Evaporation Temperature and Frequency

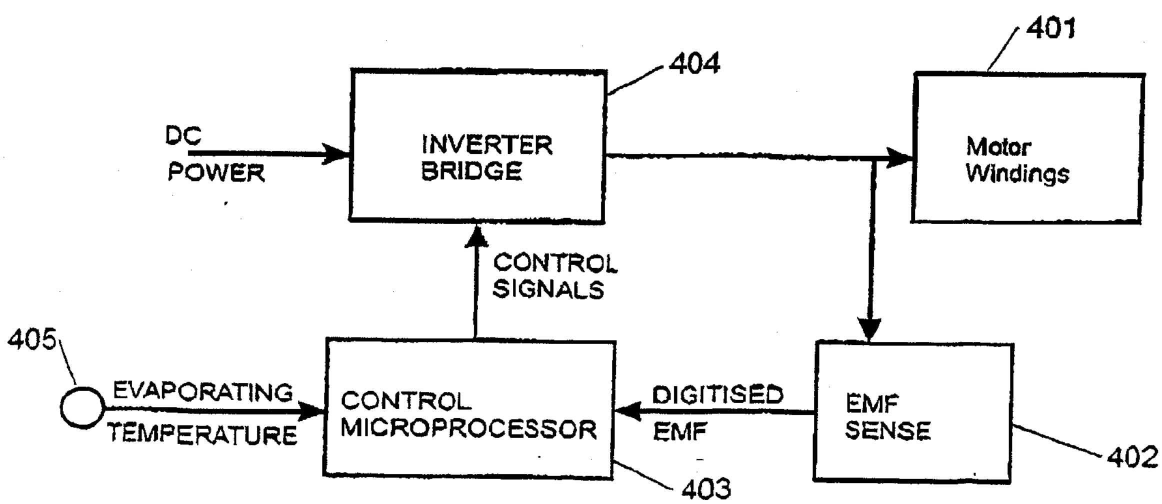


FIGURE 11

Block diagram of the motor control circuit

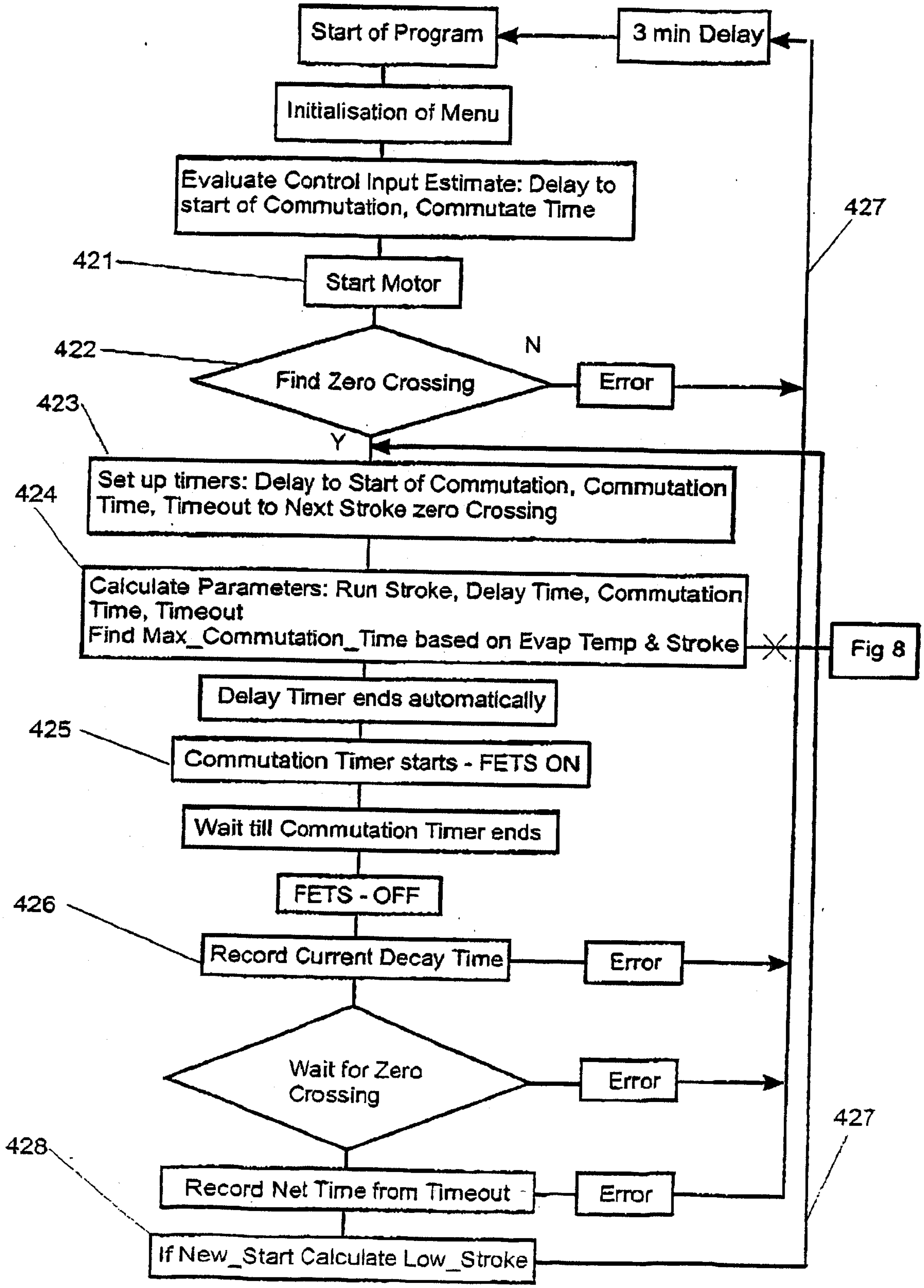


FIGURE 13

Control Microcomputer Motor Control Timing Flow Chart

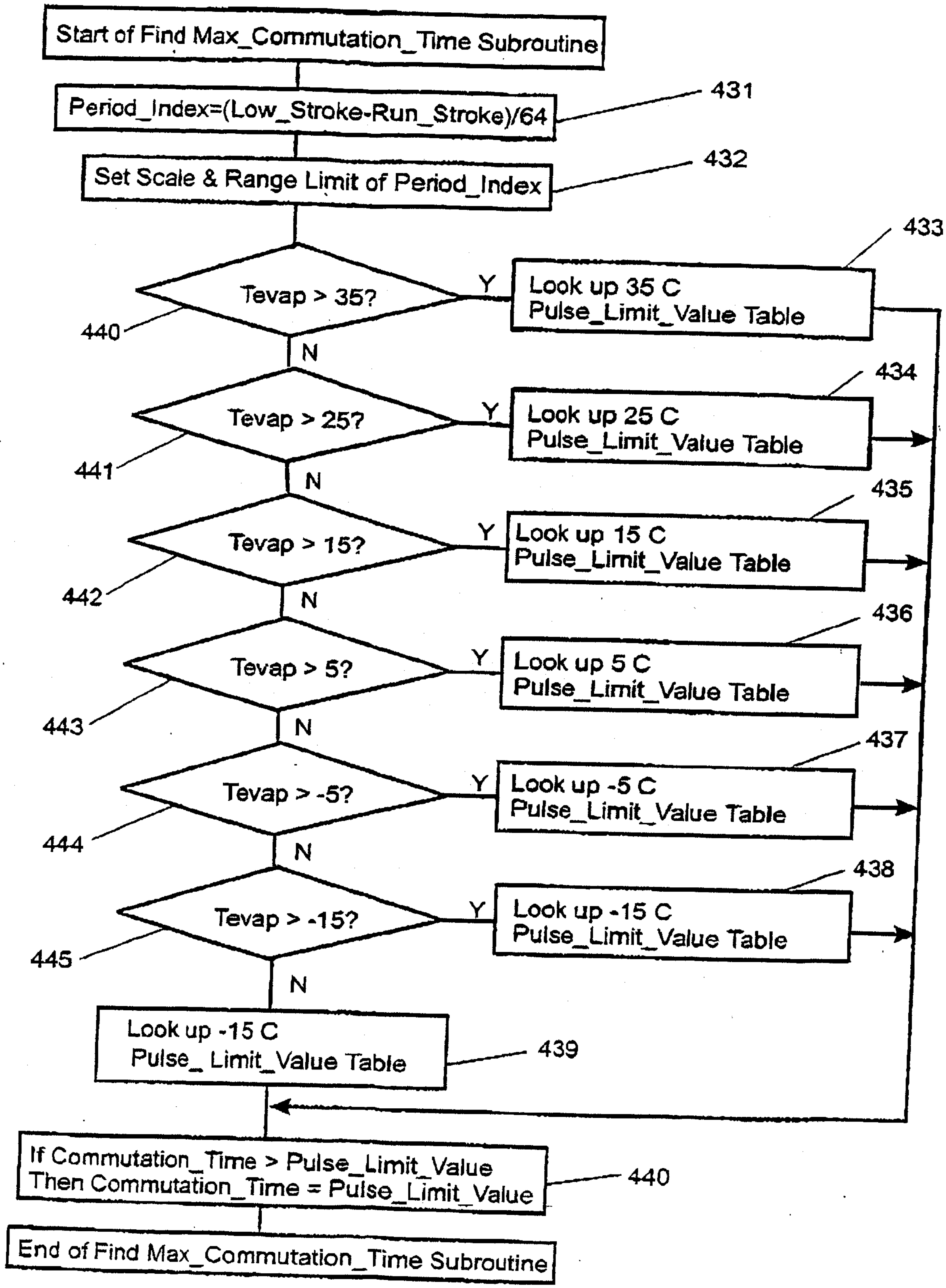


FIGURE 14

Calculation of Commutation Time Limit based on Evap Temp & Stroke Time

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ 00/00105

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl[7]: H02K 33/00, 41/02, F04B 17/04, 31/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: H02K 33/-, 41/02, F04B 17/04, 31/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPAT with key words: (MAGNET, POLE; FLUX, FIELD; AIR, GAP) and like terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 246468 A (TEXAS INSTRUMENTS INC) 25 November 1987 whole document	1, 2, 5
A	Derwent Abstract Accession No. 97-522573/48, Class X25 X27, JP 09250449 A (MATSUSHITA REIKI KK) 22 September 1997 Abstract	1, 2, 5
A	Derwent Abstract Accession No. L1266 D/43, Class X11, SU 792 511 A (BELIKOV) 30 December 1980 Abstract	1, 2, 5

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" Document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 19 October 2000	Date of mailing of the international search report 31 OCT 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200 WODEN ACT 2606 AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No.: (02) 6285 3929	Authorized officer SOOSA GNANASINGHAM Telephone No.: (02) 6283 2172

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/NZ 00/00105

Box I Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. Claims 1-5: Electric linear motor
2. Claims 6-24: Vapour compressor,

as reasoned on the extra sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/NZ 00/00105

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
EP	246468	IL	82565				
EP	726394	AU	43366/96	JP	8210247	US	5656896
EP	652632	AU	74485/94	JP	7111780	US	5658132
		JP	8066085	JP	8066043		
EP	766005	AU	62129/96	JP	9060580	US	5742492
GB	2219047	JP	1221464	US	5055011	GB	8907584
DE	3819021	JP	63252794	GB	8812931	GB	2206383
		US	4838771				
GB	2206931	JP	62295708	GB	8814371	US	4854833

END OF ANNEX

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
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(43) International Publication Date
28 December 2000 (28.12.2000)

PCT

(10) International Publication Number
WO 00/79671 A1

(51) International Patent Classification[7]: H02K 33/00, 41/02, F04B 17/04, 31/00

(21) International Application Number: PCT/NZ00/00105

(22) International Filing Date: 21 June 2000 (21.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

336375	21 June 1999 (21.06.1999)	NZ
500519	19 October 1999 (19.10.1999)	NZ

(71) Applicant *(for all designated States except US)*: **FISCHER & PAYKEL LIMITED** [NZ/NZ]; 78 Springs Road, East Tamaki, Auckland (NZ).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **DUNCAN, Gerald, David** [NZ/NZ]; 42 Henley Road, Mt Eden, Auckland (NZ). **BOYD, John, Henry** [US/US]; 57 Forest Hills Drive, Holland, MI 49424-2531 (US).

(74) Agents: **PARK, A., J.** et al.; 6th Floor, Huddart Parker Building, Post Office Square, P.O. Box 949, Wellington 6015 (NZ).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

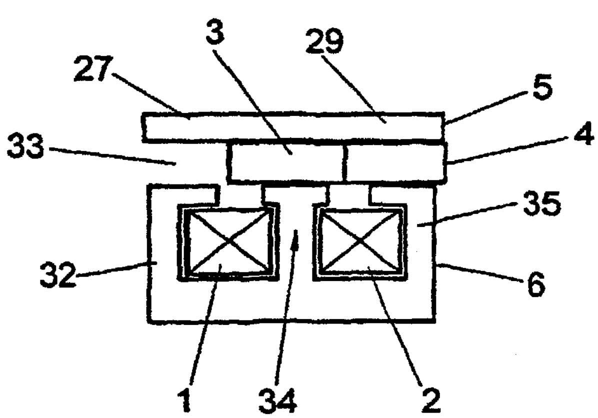
Published:

— *With international search report.*

— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LINEAR MOTOR



(57) Abstract: The present invention provides an improved design of linear motor as well as an improved control strategy. The design allows for a shorted stator, where the armature magnets are controlled to reciprocate to a greater maximum displacement than for a equivalent conventional linear motor. The control strategy is such that a minimum of external sensors are required. The linear motor is driven at its resonant frequency ensuring optionally efficient operation. A determination of the maximum current is made based on a relationship with the resonant frequency and the evaporating temperature/pressure of the vapour entering the compressor. The current is then limited to control the maximum displacement to avoid damage.

WO 00/79671 A1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ 00/00105

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl[7]: H02K 33/00, 41/02, F04B 17/04, 31/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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A	Derwent Abstract Accession No. 97-522573/48, Class X25 X27, JP 09250449 A (MATSUSHITA REIKI KK) 22 September 1997 Abstract	1, 2, 5
A	Derwent Abstract Accession No. L1266 D/43, Class X11, SU 792 511 A (BELIKOV) 30 December 1980 Abstract	1, 2, 5

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

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"A" Document defining the general state of the art which is not considered to be of particular relevance

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 October 2000	31 OCT 2000

Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200 WODEN ACT 2606 AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No.: (02) 6285 3929	SOOSA GNANASINGHAM Telephone No.: (02) 6283 2172

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ 00/00105

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0652632 A (SAWAFUJI ELECTRIC CO., LTD.), 10 May 1995 whole document	6 - 24
X	EP 0766005 A (SAWAFUJI ELECTRIC CO., LTD.), 2 April 1997 whole document	6 - 24
X	EP 0726394 A (SAWAFUJI ELECTRIC CO., LTD.), 14 August 1996 whole document	6 - 24
A	GB 2219047 A (MAN DESIGN CO LTD), 29 November 1989 whole document	6 - 24
A	DE 3819021 A (NITTO KOHKI CO LTD), 22 December 1988 whole document	6 - 24
A	GB 2206931 A (NITTO KOHKI CO LTD), 18 January 1989 whole document	6 - 24

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/NZ 00/00105

Box 1 Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

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3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

Box II

The different inventions are:

1. Claims 1-5 are directed to an electric linear motor for driving a reciprocating load wherein energising means, controlling means for producing alternating flux in the stator core is such that one end of a permanent magnet of the armature passes outside of the air gap in the stator core.

2. Claims 6-24 are directed to a vapour compressor comprising a piston reciprocating within a cylinder, a linear brushless DC motor with at least one winding coupled to the piston, electronically commutating said winding from a DC supply to reciprocate the piston, commutations timed to drive said piston at the resonant frequency of the vibrating system, which frequency varies with the vapour pressure of the compressor, wherein the parameter determining the current supply during commutation is limited to a value which is a function of said resonant frequency.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/NZ 00/00105

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
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EP	726394	AU	43366/96	JP	8210247	US	5656896
EP	652632	AU	74485/94	JP	7111780	US	5658132
		JP	8066085	JP	8066043		
EP	766005	AU	62129/96	JP	9060580	US	5742492
GB	2219047	JP	1221464	US	5055011	GB	8907584
DE	3819021	JP	63252794	GB	8812931	GB	2206383
		US	4838771				
GB	2206931	JP	62295708	GB	8814371	US	4854833

END OF ANNEX

10/018,323

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 December 2000 (28.12.2000)

PCT

(10) International Publication Number
WO 00/79671 A1

(51) International Patent Classification[7]: H02K 33/00, 41/02, F04B 17/04, 31/00

(21) International Application Number: PCT/NZ00/00105

(22) International Filing Date: 21 June 2000 (21.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
336375 21 June 1999 (21.06.1999) NZ
500519 19 October 1999 (19.10.1999) NZ

(71) Applicant *(for all designated States except US)*: **FISHER & PAYKEL LIMITED** [NZ/NZ]; 78 Springs Road, East Tamaki, Auckland (NZ).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **DUNCAN, Gerald, David** [NZ/NZ]; 42 Henley Road, Mt Eden, Auckland (NZ). **BOYD, John, Henry** [US/US]; 57 Forest Hills Drive, Holland, MI 49424-2531 (US).

(74) Agent: **A J PARK**; 6th Floor, Huddart Parker Building, Post Office Square, P.O. Box 949, Wellington 6015 (NZ).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

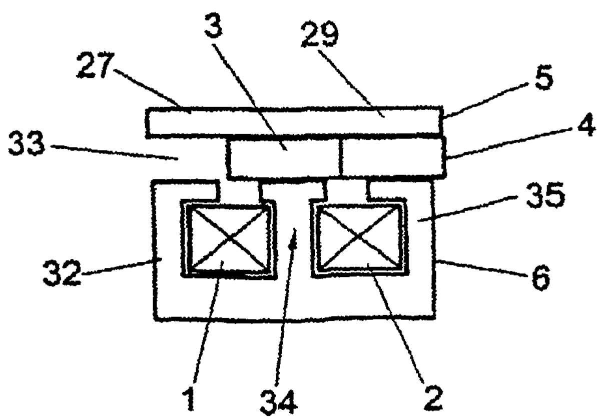
Published:
— *with international search report*

(48) Date of publication of this corrected version:
28 March 2002

(15) Information about Correction:
see PCT Gazette No. 13/2002 of 28 March 2002, Section II

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LINEAR MOTOR



(57) **Abstract:** The present invention provides an improved design of linear motor as well as an improved control strategy. The design allows for a shorted stator, where the armature magnets are controlled to reciprocate to a greater maximum displacement than for a equivalent conventional linear motor. The control strategy is such that a minimum of external sensors are required. The linear motor is driven at its resonant frequency ensuring optionally efficient operation. A determination of the maximum current is made based on a relationship with the resonant frequency and the evaporating temperature/pressure of the vapour entering the compressor. The current is then limited to control the maximum displacement to avoid damage.

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(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
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PCT

(10) International Publication Number
WO 00/79671 A1

(51) International Patent Classification⁷: H02K 33/00, 41/02, F04B 17/04, 31/00

(21) International Application Number: PCT/NZ00/00105

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(30) Priority Data:

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(71) Applicant *(for all designated States except US)*: **FISCHER & PAYKEL LIMITED** [NZ/NZ]; 78 Springs Road, East Tamaki, Auckland (NZ).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **DUNCAN, Gerald, David** [NZ/NZ]; 42 Henley Road, Mt Eden, Auckland (NZ). **BOYD, John, Henry** [US/US]; 57 Forest Hills Drive, Holland, MI 49424-2531 (US).

(74) Agents: **PARK, A., J. et al.**; 6th Floor, Huddart Parker Building, Post Office Square, P.O. Box 949, Wellington 6015 (NZ).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— *With international search report.*

— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

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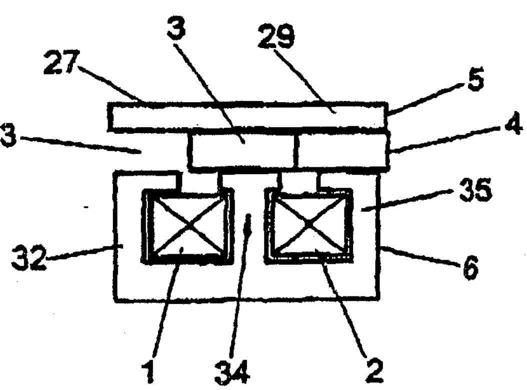

(57) Abstract: The present invention provides an improved design of linear motor as well as an improved control strategy. The design allows for a shorted stator, where the armature magnets are controlled to reciprocate to a greater maximum displacement than for a equivalent conventional linear motor. The control strategy is such that a minimum of external sensors are required. The linear motor is driven at its resonant frequency ensuring optionally efficient operation. A determination of the maximum current is made based on a relationship with the resonant frequency and the evaporating temperature/pressure of the vapour entering the compressor. The current is then limited to control the maximum displacement to avoid damage.

WO 00/79671 A1

"LINEAR MOTOR"

Technical Field

This invention relates to a compact linear motor including free piston compressors (also called vibrating and linear compressors) for vapour compression systems and in particular a control system to prevent failure or damage due to unwanted changes of compression level caused by changes to ambient temperature or operating conditions.

Background Art

Compressors, for example refrigerator compressors, are conventionally driven by rotary electric motors. However, even in their most efficient form, there are significant losses associated with the crank system that converts rotary motion to linear reciprocating motion. Alternatively a rotary compressor which does not require a crank can be used but again there are high centripetal loads, leading to significant frictional losses. A Linear compressor driven by a linear motor would not have these losses, and can be designed with a bearing load low enough to allow the use of aerostatic gas bearings as disclosed in US Patent 5,525,845.

Linear reciprocating motors obviate the need for crank mechanisms which characterise compressors powered by rotating electric motors and which produce high side forces requiring oil lubrication. Such a motor is described in US 4,602,174. US Patent 4,602,174 discloses a linear motor design that is extremely efficient in terms of both reciprocating mass and electrical efficiency. This design has been used very successfully in motors and alternators that utilise the Stirling cycle. It has also been used as the motor for linear compressors. However, in the case of compressors designed for household refrigerators the design in US 4,602,174 is somewhat larger and more costly than is desirable for this market.

The piston of a free piston compressor oscillates in conjunction with a spring as a resonant system and there are no inherent limits to the amplitude of oscillation except for collision with a stationary part, typically part of the cylinder head assembly. The piston will take up an average position and amplitude that depend on gas forces and input electrical power. Therefore for any given input electrical power, as either evaporating or condensing

pressure reduces, the amplitude of oscillation increases until collision occurs. It is therefore necessary to limit the power as a function of these pressures.

It is desirable for maximum efficiency to operate free piston refrigeration compressors at the natural frequency of the mechanical system. This frequency is determined by the spring constant and mass of the mechanical system and also by the elasticity coefficient of the gas. In the case of refrigeration, the elasticity coefficient of the gas increases with both evaporating and condensing pressures. Consequently the natural frequency also increases. Therefore for best operation the frequency of the electrical system powering the compressor needs to vary to match the mechanical system frequency as it varies with operating conditions.

Methods of synchronising the electrical voltage applied to the compressor motor windings with the mechanical system frequency are well known. For a permanent magnet motor used in a free piston compressor, a back electromotive force (back EMF) is induced in the motor windings proportional to the piston velocity as shown in Fig 8a. The equivalent circuit of the motor is shown in Fig 8b. An alternating voltage (V) is applied in synchronism with the alternating EMF (αv) in order to power the compressor. US 4,320,448 (Okuda et al.) discloses a method whereby the timing of the applied voltage is determined by detecting the zero crossings of the motor back EMF. The application of voltage to the motor winding is controlled such that the current is zero, at the time at which the EMF intersects with the zero level to allow back EMF zero crossing detection.

Various methods have been used to limit oscillation amplitude including secondary gas spring, piston position detection, piston position calculation based on current and applied voltage (US 5,496,153) measuring ambient and/or evaporating temperature (US 4,179,899, US 4,283,920). Each of these methods requires the cost of additional sensors or has some performance limitation.

DISCLOSURE OF THE INVENTION

It is an object of the present invention to provide a compact linear motor which goes some way to overcoming the abovementioned disadvantages or which will at least provide the public with a useful choice.

Accordingly in a first aspect the present invention may be said to consist in an electric linear motor for driving a reciprocating load comprising:

a stator having a magnetically permeable core with at least one air gap and means for producing a non constant magnetic flux in said stator and said at least one air gap;

an armature having a structure which supports at least one permanent magnet of which at least a substantial portion is located in at least one of said at least one air gap, such that the interaction of the magnetic field of said at least one permanent magnet and said non constant flux in said at least one air gap producing a force on said armature, said armature in use being connected to said load and thereby reciprocating with respect to said stator; and

energisation means for controlling said means for producing an alternating flux such that at least one end of said at least one permanent magnet passes outside the region of substantially uniform flux density present within said at least one of said at least one air gap during a portion of the reciprocal motion of said armature.

In a second aspect the present invention may be said to consist in a refrigerator which uses a compressor characterised in that the compressor and compressor motor are linear devices and said motor comprises:

a stator having a magnetically permeable core with at least one air gap and means for producing a non constant magnetic flux in said stator and said at least one air gap;

an armature having a structure which supports at least one permanent magnet of which at least a substantial portion is located in at least one of said at least one air gap, such that the interaction of the magnetic field of said at least one permanent magnet and said non constant flux in said at least one air gap producing a force on said armature, said armature in use being connected to said load and thereby reciprocating with respect to said stator; and

energisation means for controlling said means for producing an alternating flux such that at least one end of said at least one permanent magnet passes outside the region of substantially uniform flux density present within said at least one of said at least one air gap during a portion of the reciprocal motion of said armature.

In a third aspect the present invention may be said to consist in a vapour compressor comprising:

a piston,

a cylinder,

said piston being reciprocable within said cylinder, the vibrating system of piston, spring and the pressure of said vapour having a natural frequency which varies with vapour

pressure,

a linear brushless DC motor drivably coupled to said piston having at least one winding,

a DC power supply,

commutation means for electronically commutating said at least one winding from said DC supply to provide a supply of current to said at least one winding to reciprocate said piston,

resonant driving means which initiate commutation of said at least one winding to thereby drive said piston at the resonant frequency of said vibrating system,

current controlling means which determine the amount of said supply of current supplied by said commutation means, said determined amount of current being related to said resonant frequency, and which initiate commutation of said at least one winding to thereby limit the amplitude of reciprocation of said piston.

In a forth aspect the present invention may be said to consist in a method for driving and controlling the amplitude of the piston in a free piston vapour compressor wherein said piston reciprocates in a cylinder and wherein the vibrating system of piston, spring and the pressure of said vapour has a resonant frequency which varies with vapour pressure, said method using a linear brushless DC motor having at least one winding and comprising the steps of:

electronically commutating said at least one winding from a DC supply to reciprocate said piston, with commutations timed to drive said piston at the resonant frequency of said vibrating system, limiting the amount of current in said at least one winding by limiting the value of a parameter which determines current supply during commutation to a value which is a function of said resonant frequency.

The "evaporating temperature of the vapour entering the compressor" is also referred to in this specification as the "evaporator temperature". Likewise the "resonant frequency" is also referred to as the "natural frequency".

To those skilled in the art to which the invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the scope of the invention as defined in the appended claims. The disclosures and the descriptions herein are purely illustrative and are not intended to be in

any sense limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-section of a linear compressor according to the present invention;

Figure 2 is a cross-section of the double coil linear motor of the present invention in isolation;

Figure 3 is a cross-section of a single coil linear motor;

Figure 4 is a comparison between a single window prior art linear motor and a short stator linear motor according to the present invention;

Figure 5 is an illustration of the flux lines due to the coil current in a single coil linear motor of the present invention;

Figure 6 is a graph of the motor constant versus magnet position for the preferred embodiment of the present invention;

Figure 7 is a cross-section of a single coil linear motor with partially angled pole faces;

Figure 8a shows motor piston displacement and back EMF waveforms for a free piston compressor motor;

Figure 8b shows an equivalent circuit for such a motor;

Figure 9 shows an inverter for electronically commutating a single phase free piston motor;

Figure 10 shows graphs of maximum motor current as a function of frequency and evaporation temperature for a motor of the present invention;

Figure 11 is a block diagram of the motor control circuit;

Figure 12 is a graph of RMS motor current versus motor winding current decay time;

Figure 13 is a flow chart of the motor control timing program;

Figure 14 is a flow chart of commutation time determination using evaporator temperature and stroke time data; and

Figure 15 shows motor piston displacement and motor current waveforms.

MODE(S) FOR CARRYING OUT THE INVENTION

The present invention provides a method for controlling a linear motor with a number of improvements over the prior art. Firstly it has a reduced size compared to the conventional linear motor of the type described in US4602174 and thus reduces the cost.

This change keeps the efficiency high at low to medium power output at the expense of slightly reduced efficiency at high power output. This is an acceptable compromise for a compressor in a household refrigerator which runs at low to medium power output most of the time and at high power output less than 20% of the time (this occurs during periods of frequent loading and unloading of the refrigerator contents or on very hot days). Secondly it uses a control strategy which allows optimally efficient operation, while negating the need for external sensors, which also reduces size and cost.

While in the following description the present invention is described in relation to a cylindrical linear motor it will be appreciated that this method is equally applicable to linear motors in general and in particular also to flat linear motors. One skilled in the art will require no special effort to apply the control strategy herein described to any form of linear motor. It will also be appreciated that the present invention will be applicable in any form of compressor. While it is described in relation to a free piston compressor it could equally be used in a diaphragm compressor.

A practical embodiment of the invention, shown in Figure 1, involves a permanent magnet linear motor connected to a reciprocating free piston compressor. The cylinder 9 is supported by a cylinder spring 14 within the compressor shell 30. The piston 11 is supported radially by the bearing formed by the cylinder bore plus its spring 13 via the spring mount 25.

The reciprocating movement of piston 11 within cylinder 9 draws gas in through a suction tube 12 through a suction port 26 through a suction muffler 20 and through a suction valve port 24 in a valve plate 21 into a compression space 28. The compressed gas then leaves through a discharge valve port 23, is silenced in a discharge muffler 19, and exits through a discharge tube 18.

The compressor motor comprises a two part stator 5,6 and an armature 22. The force which generates the reciprocating movement of the piston 11 comes from the interaction of two annular radially magnetised permanent magnets 3,4 in the armature 22 (attached to the piston 11 by a flange 7), and the magnetic field in an air gap 33 (induced by the stator 6 and coils 1,2).

A two coil embodiment of present invention, shown in Figure 1 and in isolation in Figure 2, has a current flowing in coil 1, which creates a flux that flows axially along the

inside of the stator 6, radially outward through the end stator tooth 32, across the air gap 33, then enters the back iron 5. Then it flows axially for a short distance 27 before flowing radially inwards across the air gap 33 and back into the centre tooth 34 of the stator 6. The second coil 2 creates a flux which flows radially in through the centre tooth 34 across the air gap axially for a short distance 29, and outwards through the air gap 33 into the end tooth 35. The flux crossing the air gap 33 from tooth 32 induces an axial force on the radially magnetised magnets 3,4 provided that the magnetisation of the magnet 3 is of the opposite polarity to the other magnet 4. It will be appreciated that instead of the back iron 5 it would be equally possible to have another set of coils on the opposite sides of the magnets.

An oscillating current in coils 1 and 2, not necessarily sinusoidal, creates an oscillating force on the magnets 3,4 that will give the magnets and stator substantial relative movement provided the oscillation frequency is close to the natural frequency of the mechanical system. This natural frequency is determined by the stiffness of the springs 13, 14 and mass of the cylinder 9 and stator 6. The oscillating force on the magnets 3,4 creates a reaction force on the stator parts. Thus the stator 6 must be rigidly attached to the cylinder 9 by adhesive, shrink fit or clamp etc. The back iron is clamped or bonded to the stator mount 17. The stator mount 17 is rigidly connected to the cylinder 9.

In a single coil embodiment of the present invention, shown in Figure 3, current in coil 109, creates a flux that flows axially along the inside of the inside stator 110, radially outward through one tooth 111, across the magnet gap 112, then enters the back iron 115. Then it flows axially for a short distance before flowing radially inwards across the magnet gap 112 and back into the outer tooth 116. In this motor the entire magnet 122 has the same polarity in its radial magnetisation.

In the preferred embodiment of the present invention the length of the armature (tooth) faces only extends to, for example, 67% of the maximum stroke (where the edge of the magnet extends to at maximum power output) of the magnet. This is seen in Figure 4 where a conventional prior art linear motor is visually compared against the present invention variable constant design of equivalent power output, both at maximum stroke. It can be seen that the outer edge 200 of the stator tooth does not extend as far as the outer end of the magnet 201. Similarly the inner edge 203 of the other stator tooth does not extend to the inner end of the magnet 204. In contrast in the prior art design the edge of the magnet 205

does match up with the edges of the stator teeth 206,207 at maximum stroke.

At strokes less than, for example, 60% in the present invention the magnet 70 will be in an area of uniform flux density as indicated by the region "a" to "b" in Figure 5, which roughly corresponds where the stator teeth 71 extend to. As the stroke increases past 60% the flux density encountered by the magnet edge 70 reduces as it enters the fringe portion (non-uniform flux density) of the air gap magnetic field - the area outside "b" in Figure 5.

In a further embodiment shown in Figure 7, a stator for a linear motor is shown with angled pole face 503. In its centre the pole face 503 has a flat section 500, which results in the air gap facing that section having substantially uniform flux density. The end of the pole face 503, is angled to give a more progressive transition from the uniform flux density of the centre 500, to the fringe portion 502 (non-uniform flux density) at the end of the pole face 503. Similar to the proceeding embodiments the armature magnet 504, would be driven outside the area of uniform flux density 500, and into the fringe portion 502 of non-uniform flux density.

The "Motor Constant" is defined as the force (in Newtons) generated on the magnet by one Ampere in the motor windings. The motor constant curve, shown in Figure 6 shows how the Motor Constant 300 for the present invention varies with magnet position. Equally the "Motor Constant" can be defined as the back EMF (in Volts) generated when the magnet is moving at one metre/second. When the magnet is in the fringe field (outside "b" in Figure 5), because of the reduced magnetic coupling, more current will be required to generate a given force when compared to that in the uniform flux region (from "a" to "b" in Figure 5). This results in the "variable" motor constant curve 300 associated with the present invention short stator linear motor as shown in Figure 6. This contrasts with the "constant" motor constant curve 301, also seen in Figure 6, inherent in the conventional prior art linear motors.

With the motor constant curve 300 shown in Figure 6 at low and medium strokes (corresponding to strokes of -3mm to +3mm) it will be apparent the present invention has a high motor constant relative to an equivalent convention motor 301, (with less turns and a greater volume of core material). A higher motor constant corresponds to more efficient operation (due to lower invertor losses), therefore at lower power output the present invention is more efficient than an equivalent conventional prior art linear motor. It also

reduces the required cross sectional area of the core.

At high strokes the motor constant is low at the times when the current is increasing most rapidly. This makes it possible to get more current into the motor and thus extract more power from the motor at maximum strokes as compared to an equivalent conventional prior art linear motor. Also such a design with a variable constant that is lowest at maximum stroke tends to make motors driven by square wave voltages more efficient.

Control Strategy

Experiments have established that a free piston compressor is most efficient when driven at the natural frequency of the compressor piston-spring system. However as well as any deliberately provided metal spring, there is an inherent gases spring, the effective spring constant of which, in the case of a refrigeration compressor, varies as either evaporator or condenser pressure varies. The electronically commutated permanent magnet motor already described, is controlled using techniques including those derived from the applicant's experience in electronically commutated permanent magnet motors as disclosed in US 4857814 and WO 98/35428 for example, the contents of which are incorporated herein by reference. Those references disclose the control of a 3 phase rotating motor, but the same control principles can be applied to linear motors. A suitable linear motor need only be a single phase device and a suitable inverter bridge circuit for powering a motor can be of the simple form shown in Figure 9.

By monitoring back EMF zero crossings in the motor winding current commutation can be determined to follow the natural frequency of the piston. Since there is only a single winding, the current flowing through either upper or lower inverter switching devices 411 or 412 must be interrupted so that back EMF can be measured. Controlling the current through the motor winding in accordance with detected back EMF ensures current and back EMF are maintained in phase for maximum system efficiency.

The frequency of operation of the motor is effectively continuously monitored as frequency is twice the reciprocal of the time between back EMF zero crossings. Furthermore according to WO 98/35428 the current decay time through free wheel diodes 413 and 414 after commutation has ceased is directly proportional to the motor current and thus a measure of motor current is available.

The maximum motor current that can be employed before the piston collides with the

cylinder head of the compressor varies depending upon the evaporator temperature and the natural frequency of the vibrating system

Figure 10 shows graphs of maximum permitted motor current against natural mechanical system frequency and condenser temperatures for different evaporating temperatures. These show the dependence of maximum motor current on both these variables. They also demonstrate that condenser temperatures are proportional to mechanical system frequency and thus maximum current control can be achieved without the need for measurement of the third variable, condenser temperature.

The motor control circuit according to this invention is shown in Figure 11. It utilises the observation that mechanical system frequency is related to condenser temperature. In this invention the back EMF signal induced in the motor windings 1 is sensed and digitised by circuit 402 and applied to the input of a microcomputer 403 which computes the appropriate timing for the commutation of current to the motor windings to ensure that the current is in phase with the back EMF. These commutation timing signals switch an inverter 404 (as shown in Figure 11) which delivers current to the motor windings 401. The microcomputer 403 also measures the time between back EMF zero crossings and thereby the period of the EMF waveform. The natural oscillation frequency of the mechanical system is the inverse of the period of the EMF waveform. The microcomputer 403 therefore has a measure of this frequency at all times.

The conventional temperature sensor 405 for measuring the evaporator temperature for defrost purposes is utilised and its output is digitised and supplied as a further input to microcomputer 403.

According to the present invention one method of limiting maximum motor current and thus maximum displacement of the piston is for the microcomputer 403 to calculate a maximum current amplitude for each half cycle of piston oscillation and limit the actual current amplitude to less than the maximum. WO 98/35428 discloses a method of measuring motor current in an electronically commutated permanent magnet motor by utilising the digitised back EMF signal in an unpowered winding to measure the time taken for the current in the motor winding to decay to zero. Use of this technique in the present invention enables microcomputer 403 to limit maximum power without the need for dedicated current sensing or limiting circuitry. The RMS motor current is directly proportional to the time duration of

current decay through the "freewheeling" diodes 413 or 414 after the associated inverter switching device has switched off. The current decay results of course from the motor winding being an inductor which has stored energy during commutation and which must be dissipated after commutation has ceased. A graph of RMS motor current against current decay duration (which is a simplification of Figure 6 in WO 98/35428) is shown in Figure 12.

Another preferred method is to limit the time that the current is commutated on instead of limiting the maximum current value. Figure 15 shows the current waveform under such control. This is in effect pulse width modulation (PWM) with only one modulated current pulse per commutation interval. With this method a delay time from the back EMF zero crossing is computed to minimise the phase angle between the Motor Current and the back EMF for maximum efficiency. The invertor switch supplying current is turned off at a time in the motor half cycle to allow, after a current decay period, time to monitor zero crossing of the back EMF to determine the start commutation for the next half cycle. The commutation time is also compared with a maximum commutation time appropriate to the motor frequency and evaporator temperature to ensure maximum amplitude of the piston stroke is not exceeded.

A flow diagram of the microcomputer control strategy to implement this method is shown in Figures 13 and 14. Referring to Figure 13 when the compressor is first powered (421), or is powered after sufficient time delay to ensure pressures are equalised in the refrigeration system, the compressor runs at a minimum frequency. The stroke period of this minimum frequency is measured as Run_Stroke and shown in the microcomputer as Low_Stroke and a minimum Commutation Time is set for this value (428). For each subsequent stroke the stroke period is measured and defined as the parameter Run_Stroke (424). The difference between Run_Stroke and Low_Stroke is computed (431, Figure 14). This difference is called Period_Index. The Period_Index is used in this sub-routine as an index pointer in a lookup table of maximum commutation times for different stroke times (frequencies). This table is called the Pulse_Limit_Value Table. In this instance there are 7 lookup tables (433 to 439) corresponding to 7 ranges of Evaporating Temperature (440 to 465).

The motor control circuit is typically included in a Temperature Control loop in the

conventional manner in order to maintain the temperature of the enclosed refrigerated space of the refrigeration system. This control loop will be setting desired values for the power to be applied to the motor windings depending on the operating conditions of the refrigeration system. These values of desired power will correspond to values of commutation time. These values of Commutation Time are compared on a stroke by stroke basis with the Pulse_Limit_Value (440, Figure 14). If the Desired value of commutation time is greater than the Pulse_Limit_Value then the commutation time is limited to the Pulse_Limit_Value. This value sets the Commutation Timer (425) which controls the ON period of the relevant inverter switching device. As previously explained, Motor current can also be used in a similar manner to limit power applied to the motor to safe levels, but even where commutation time is being controlled it is desirable to measure motor current in the manner previously described and compare it with a stored absolute maximum value (426) which if exceeded will cause the microcomputer program to reset (427).

Of course other methods of determining maximum commutation time and/or maximum current value are feasible, for instance if the microcomputer is sufficiently powerful, for example recent advances in DSP chip technology, these values can be computed directly without the need for lookup tables.

If the DC power supply Voltage supplied to the inverter bridge of Figure 9 varies significantly this will result in variation of Motor Current for any given commutation time which should be allowed for. It may be desirable for maximum accuracy for the microprocessor to sense this and compensate accordingly.

It will be appreciated that use of the present invention in a refrigerator reduces the profile, size and weight of the motor compared to that of conventional designs. Also because the mass of the moving parts is lower than that of a conventional refrigerator compressor:

- the level of vibration is reduced,
- the noise level is reduced,
- the working stresses on the moving parts are reduced.

CLAIMS:

1. An electric linear motor for driving a reciprocating load comprising:

a stator having a magnetically permeable core with at least one air gap and means for producing a non constant magnetic flux in said stator and said at least one air gap;

an armature having a structure which supports at least one permanent magnet of which at least a substantial portion is located in at least one of said at least one air gap, such that the interaction of the magnetic field of said at least one permanent magnet and said non constant flux in said at least one air gap producing a force on said armature, said armature in use being connected to said load and thereby reciprocating with respect to said stator; and

energisation means for controlling said means for producing an alternating flux such that at least one end of said at least one permanent magnet passes outside the region of substantially uniform flux density present within said at least one of said at least one air gap during a portion of the reciprocal motion of said armature.

2. An electric linear motor as claimed in claim 1 wherein said means for producing an alternating magnetic flux comprises at least one coil wound around a portion of said stator and energised with a non constant voltage.

3. An electric linear motor as claimed in claim 2 wherein said energisation means comprises a commutation circuit including a direct current power supply, switching devices connected to said power supply to supply current to said at least one coil and a programmed digital processor including memory and input-output ports, at least one of said ports being connected to said commutation circuit to supply switching control signals thereto.

4. An electric linear motor as claimed in claim 1 wherein the displacement of said at least one permanent magnet at which said at least one end of said at least one magnet passes outside said region of substantially uniform flux density is 67% of the maximum displacement.

5. A refrigerator which uses a compressor characterised in that the compressor and

compressor motor are linear devices and said motor comprises:

a stator having a magnetically permeable core with at least one air gap and means for producing a non constant magnetic flux in said stator and said at least one air gap;

an armature having a structure which supports at least one permanent magnet of which at least a substantial portion is located in at least one of said at least one air gap, such that the interaction of the magnetic field of said at least one permanent magnet and said non constant flux in said at least one air gap producing a force on said armature, said armature in use being connected to said load and thereby reciprocating with respect to said stator; and

energisation means for controlling said means for producing an alternating flux such that at least one end of said at least one permanent magnet passes outside the region of substantially uniform flux density present within said at least one of said at least one air gap during a portion of the reciprocal motion of said armature.

6. A vapour compressor comprising:

a piston,

a cylinder,

said piston being reciprocable within said cylinder, the vibrating system of piston, spring and the pressure of said vapour having a natural frequency which varies with vapour pressure,

a linear brushless DC motor drivably coupled to said piston having at least one winding,

a DC power supply,

commutation means for electronically commutating said at least one winding from said DC supply to provide a supply of current to said at least one winding to reciprocate said piston,

resonant driving means which initiate commutation of said at least one winding to thereby drive said piston at the resonant frequency of said vibrating system,

current controlling means which determine the amount of said supply of current supplied by said commutation means, said determined amount of current being related to said resonant frequency, and which initiate commutation of said at least one winding to thereby limit the amplitude of reciprocation of said piston.

7. A vapour compressor as claimed in claim 6 further comprising:

a sensor for measuring a property of the vapour entering the compressor which is an indicator of the pressure,

and wherein said determined amount of current also being related to said measured indicative property.

8. A vapour compressor as claimed in claim 7 wherein said sensor measures a property of the vapour entering the compressor which is an indicator of the pressure on evaporation.

9. A vapour compressor as claimed in any one of claims 6 to 8 wherein said resonant driving means comprising:

back EMF detection means for sampling the back EMF induced in said at least one winding when commutation current is not flowing and for detecting back EMF zero-crossings and producing timing signals derived therefrom, and

resonant commutation means which initiate commutation of said at least one winding in response to said zero crossing timing signals to thereby drive said piston at the resonant frequency of said vibrating system.

10. A vapour compressor as claimed in claim 9 further comprising

current detection means for measuring the current flowing in said at least one winding during commutation,

wherein said current controlling means terminates commutation when said measured current reaches said determinated amount of current.

11. A vapour compressor as claimed in claim 10 wherein said commutation means includes switching devices connected to said DC power supply to supply current to said at least one winding and unidirectional current devices which supply a current path to dissipate energy stored in each winding after supply of current through a switching device has terminated, and said current detection means comprises:

a programmed digital processor including memory and input-output ports, a first port being connected to the output of said back EMF detection means and a second group of ports

being connected to said commutation means to supply switching control signals thereto,

software stored in said memory to cause said processor to determine a measure of motor current based on intervals between those zero crossings of said back EMF, which represent the duration of a current pulse produced in said at least one winding due to dissipation of stored energy by said unidirectional current devices after supply of current has been removed from said at least one winding.

12. A vapour compressor as claimed in any one of claims 6 to 11 wherein said current controlling means further comprises:

means for measuring said resonant frequency,

a memory which stores at least one look up table containing maximum current commutation values for each of a plurality of resonant frequencies for said vibrating system, and

value selection means for selecting the value in said table which corresponds to said measured resonant frequency and for supplying same to said commutation controlling means.

13. A vapour compressor as claimed in either claims 7 or 8 wherein said current controlling means further comprising:

means for measuring said resonant frequency,

a memory which stores a plurality of look up tables stored in said memory containing maximum current commutation values for each of a plurality of resonant frequencies for said vibrating system, each look up table corresponding to a non-overlapping range of said indicative property, and

table selection means for selecting a look up table to use on the basis of the measured value of said indicative property,

value selection means for selecting the value in said table which corresponds to said measured resonant frequency and for supplying same to said commutation controlling means.

14. A vapour compressor as claimed in any one of claims 6 to 11 wherein said current controlling means includes a processor storing instructions which when executed calculate said determined amount of current based on a mathematically expressible relationship to at

least said measured resonant frequency and optionally said measured indicative property.

15. A method for driving and controlling the amplitude of the piston in a free piston vapour compressor wherein said piston reciprocates in a cylinder and wherein the vibrating system of piston, spring and the pressure of said vapour has a resonant frequency which varies with vapour pressure, said method using a linear brushless DC motor having at least one winding and comprising the steps of:

electronically commutating said at least one winding from a DC supply to reciprocate said piston, with commutations timed to drive said piston at the resonant frequency of said vibrating system, limiting the amount of current in said at least one winding by limiting the value of a parameter which determines current supply during commutation to a value which is a function of said resonant frequency.

16. A method as claimed in claim 15 further comprising the step of measuring a property of the vapour entering the compressor which is an indicator of the pressure, wherein said selected maximum current commutation value is also a function of said measured indicative property.

17. A method as claimed in claim 16 wherein said measured indicative property is an indicator of the pressure on evaporation.

18. A method as claimed in any one of claims 15 to 17 wherein said step of driving said piston at the resonant frequency of said vibrating system comprises the steps of:

unpowering said at least one winding at various intervals and detecting zero-crossings of the back EMF induced in said at least one winding, using the zero-crossing timing information to initiate commutation of said at least one winding to thereby drive said piston at the resonant frequency of said vibrating system.

19. A method as claimed in claim 18 wherein said step of electronic commutation comprises using commutation means includes switching devices connected to said DC power supply to supply current to said at least one winding and unidirectional current devices which

supply a current path to dissipate energy stored in each winding after supply of current through a switching device has terminated, measuring motor current based on intervals between those zero crossings of said back EMF, which represent the duration of a current pulse produced in said at least one winding due to dissipation of stored energy by said unidirectional current devices after supply of current has been removed from said at least one winding, and terminating commutation when said measured current reaches said determinated amount of current.

20. A method as claimed in either claims 16 or 17 further comprising a step of measuring a property of the vapour entering the compressor which is an indicator of the pressure on evaporation, wherein said maximum current commutation value is selected from one of a set of look up tables containing maximum current commutation values for each of a plurality of resonant frequencies for said vibrating system and selecting the value which corresponds to the measured resonant frequency, each look up table corresponding to a non-overlapping range of said indicative property and being selected on the basis of the measured value of said indicative property.

21. A method according to claim 20 wherein said parameter which is limited is the magnitude of the current and said look up tables store maximum current values.

22. A method according to claim 20 wherein parameter which is limited is the duration of commutation and said look up tables store maximum commutation duration values.

23. A vapour compressor according to claim 6 wherein instead of said piston and said cylinder said compressor is a diaphragm type compressor.

24. A method according to claim 15 wherein instead of said piston and said cylinder said compressor is a diaphragm type compressor.